THE 3R ANTHRACITE CLEAN COAL TECHNOLOGY
Economical Conversion of Browncoal to Anthracite Type Clean Coal by Low Temperature Carbonization Pre-Treatment Process

by

Edward SOMEUS

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The preventive pre-treatment of low grade solid fuels is safer, faster, better, and less costly vs. the "end-of-the-pipe" post treatment solutions. The "3R" (Recycle-Reduce-Reuse) integrated environment control technology provides preventive pre-treatment of low grade solid fuels, such as brown coal and contaminated solid fuels to achieve high grade cleansed fuels with anthracite and coke comparable quality. The goal of the 3R technology is to provide cost efficient and environmentally sustainable solutions by preventive pre-treatment means for extended operations of the solid fuel combustion power plants with capacity up to 300 MW_e power capacities. The 3R Anthracite Clean Coal end product and technology may advantageously be integrated to the oxyfuel – oxy-firing, Foster Wheeler anthracite arc-fired utility type boiler and Heat Pipe Reformer technologies in combination with CO_2 capture and storage programs. The 3R technology is patented original solution.
Advantages. Feedstock flexibility: application of pre-treated multi fuels from wider fuel selection and availability. Improved burning efficiency. Technology flexibility: efficient and advantageous interlink to proven boiler technologies, such as oxyfuel and arc-fired boilers. Near zero pollutants for hazardous-air-pollutants: preventive separation of halogens and heavy metals into small volume streams prior utilization of cleansed fuels. 97% organic sulphur removal achieved by the 3R thermal pre-treatment process. Integrated carbon capture and storage (CCS) programs: the introduction of monolitic GHG gas is improving storage safety. The 3R technology offers significant improvements for the GHG CCS conditions. Cost reduction: decrease of overall production costs when all real costs are calculated. Improved safety: application of preventive measures.
For pre-treatment a specific purpose designed, developed, and patented pyrolysis technology used, consisting of a horizontally arranged externally heated rotary kiln. The flexible operation provides wide range of 25 to 125% of nominal capacities. The volatile hazardous air pollutants are safely removed in the reduced volume of gas-vapour stream and burned out in the post burner at 850 C^{2s} ^{50} C, while the Clean Coal solid end product is utilized for clean energy production. "Product like" pilot plant with 100 kg/h through-put capacity has been built and successfully tested in Hungary in 2005.
The 3R anthracite Clean Coal technology opens new technological and economical opportunities for solid fuel power generation with sustainable near zero emission performance and safe CCS operations. The 3R technology provides revolutionary solution for climate impact prevention, protection and preservation by safety improvement of the optimized GHG storage conditions. Achievable goal: safe CCS with zero emission seepage. The input 3R CO_2 for CCS geological structure injection is clean, low in volume and high in concentration, all in order to optimize the "once for all" stabilized chemical fixation of the CO_2, to the mineral matrix.

Key words: *Clean Coal, anthracite, coke, pyrolysis, thermolysis, carbonization, pre-treatment, prevention, oxyfuel, arc-fired, carbon capture, storage, CCS, GHG, green house gases, climate, hazardous air pollutants, sulphur*

Introduction

The solid fuel based energy production is one of the critical elements of the sustainable economy. At an annual production rate of about 3.5 billion metric tons coal worldwide, serious depletion of resources will take several hundred years.

Most of the coal reserves are located within the stabile Western world, and the U. S. has approximately 31% of the known recoverable coal reserves of the world.

The highest grade of coal reserves – the anthracite, also known as smokeless fuel – is less than 1% of the total coal reserves.

The Anthracite Clean Coal is a natural product created as a result of the thousands of years of carbonization process. This is the highest grade of coals, with high content of fixed carbon and low percentage of moisture and volatile matter (less than 8 percent). It contains little or no bitumen, and therefore burns with an almost invisible flame. This fuel is nearly pure carbon and burns with a clean flame and little smoke or odor. Gross heating values are 30 to 33 MJ/kg (as received basis). Anthracite delivers high energy per weight and burns cleanly with little or no soot. Although anthracite is difficult to ignite, having higher ignition and ash fusion temperatures, it burns with a pale-blue flame and requires little attention to sustain combustion.

Due to its low volatile matter content and non-clinkering characteristics, anthracite coal is primarily used in small and medium-sized industrial and institutional stoker boilers, equipped with stationary or traveling grates. This fuel may also be burned in pulverized and fluidized bed coal-fired units. Special furnace arc design is required to assist in the ignition of the "green fuel".

Foster Wheeler has sold 49 arc-fired utility type boilers representing an equivalent electricity capacity of 10,377 MW_e for burning low volatile type anthracites and blends. Forty-one of these boilers have been in operation for many years. Twenty-three are in the size range over 100 MW_e with a total equivalent capacity of 5130 MW_e.

These advantageous characteristics makes anthracite the most valuable of the coals. However it is seldom used alone because of the high cost due to the low coal reserve availability.

Due to the new environmental regulations and Kyoto Protocol requirements for control of green house gas emissions, there is a need for significant and urgent improvement of the overall emission and environmental performance of the solid fuel power generation. The "green" upgrade of the power plant's main and the "end-of-the-pipe" off-gas treatment technologies are continuously ongoing, but – despite high financial investments – are far not sufficient.

The further environmental improvements on the solid fuel utilization technologies requires highly increased financial investments, resulting in significant increase of the energy costs, which might have negative and slowing effect on the development.

Consequently many traditional solid fuel utilization technologies have already reached their ultimate technical and economical possibilities.

The 3R technology opens new technical and economical opportunities by refining low grade coals to high grade anthracite coal and coke comparable fuel by application of pre-treatment low temperature carbonization and its output emission performance supporting the safer CCS.

General coal fuel characterization

Coal feed streams may vary in chemical-physical composition and energetic content. While there is a requirement for continuous improvement of process and cost efficiency, at the same time there is a dedicated and progressive international requirement for improvement of the environmental performance of solid fuel power generation for operating and new power plants as well. These improving environmental standards targeting significant emission decrease from the solid fuel power plants and clearly indicating tendencies for moving towards near zero emissions.

The main concerns of the solid fuel power plant's environmental performance are the hazardous air target pollutants (HAP) – sulphur, mercury chlorine – and the greenhouse gases such as CO_2.Therefore, highly flexible solid fuel technologies need to be developed and applied to achieve comprehensive benefits as follows: feedstock flexibility, near zero pollutants, safer CCS, improved safety, improved burning efficiency, cost reduction, and comprehensive residual utilization.

Highlight on halogen problems

Many British studies have associated accelerated fireside corrosion of heat exchanger tubes in utility boilers with the high-Cl content in the fuel coal. British literature, correlating superheater/reheater corrosion in boilers with the total Cl content in coals, has led many boiler manufacturers to set their recommended Cl level at 0.25 to 0.3% for burning coals. However, Cl-related boiler corrosion has not been reported by the U. S. utilities burning high-Cl Illinois coals. This means other factors, such as sulphur, alkali metals, or boiler parameters, may be responsible for accelerated corrosion. In many developed countries, coal combustion is the largest source of Cl from human activities and may also be a predominant source of fluorine. Emissions from coal combustion are in the form of highly soluble acidic gases, which can contribute to acid rain.

Highlight on mercury emission problem

Mercury and selenium, present as traces in coal, are readily volatilized during coal combustion. These are the most volatile among various trace metals, and major portions of these metals can pass through existing particulate control devices. The mercury emissions from coal combustion are considered to be of environmental concern. Extensive studies provides scientifically information, that mercury emissions from coal fired power plants pose significant hazards to public health, and mercury from power plants settles over waterways, polluting rivers and lakes, and contaminating fish. Exposure to mercury poses real risks to public health, especially to children and developing fetuses[*].

[*] Reference report: Mercury Falling: An Analysis of Mercury Pollution from Coal Burning Power Plants, authored by the US Environmental Working Group, Clean Air Network and the Natural Resources Defense Council

The greatest source of mercury emissions is coal-fired power plants. Exposure to mercury has been associated with both neurological and developmental damage in humans. The developing fetus is the most sensitive to mercury's effects, which include damage to nervous system development. People are exposed to mercury primarily through eating fish that have been contaminated when mercury from power plants and other sources is deposited to water bodies. Once mercury enters water, biological processes can transform it into methyl mercury, a highly toxic form of mercury that builds up in animal and human tissues.

Mercury in its various chemical forms is a difficult element to measure at low concentrations. Reliable data on mercury emissions are therefore sparse. Some data suggest that the concentration of mercury in the atmosphere is increasing, some that it may be decreasing. Mercury pollution in remote lakes in Scandinavia is reported to be increasing and some fish stocks are becoming contaminated.

Mercury emissions from coal utilization are reviewed as well as control options. The specification of mercury, oxidized or elemental, dictates it emissions and effects. Oxidized mercury is soluble and has a tendency to associate with particles. Emissions of oxidized mercury may be efficiently controlled by some flue gas desulphurization (FGD) systems. Some activated carbons have the potential to control the oxidized mercury. Any oxidized mercury escaping from the stack is deposited on a local or regional scale. On the other hand, elemental mercury is extremely volatile and insoluble and is not captured by FGD systems. Elemental mercury may be removed by some chemically treated activated carbons or selective sorbent but these are only currently being tested at pilot scale on coal-fired power stations, where the application is expected to be very costly. Elemental mercury travels hundreds of miles and contributes to the increasing atmospheric load.

The 3R anthracite Clean Coal process

The 3R^{TM} (Thermal Desorption Technology Recycle-Reduce-Reuse) Low Temperature Carbonization Process Clean Coal technology represents the advanced generation of solid feedstock-based energy production systems: by pre-treatment it breaks down any carbon-based feedstock into its basic constituents and remove contamination by preventive measure. This enables the preventive separation of HAP's to produce clean gas for efficient and improved electricity generation.

The 3R technology may be applied as vital component for an integrated strategy towards near zero emission targets to combine technologies for environmentally sustainable and economical solid fuel power generation, including but not limited to the decrease or even removal of output green house gases, such as CO_2.

The 3R pyrolysis technology

The main component of the 3R technology is a specially designed, patented, indirectly fired rotary reactor in which waste in a reductive environment is partially vaporized and/or gas-out in low vacuum (0-50 Pa) between the temperature ranges of 400-650 C. The gas-vapours from the reductive decomposing process is directly combusted at min. 850 °C^{2s}, fast cooled and heat from its flue gas recovered (fig. 1).

The hearth of the 3R technology is the unique pyrolysis rotary kiln design, which makes viable the reductive thermal decomposition – low temperature carbonization – of any organic feed material under stable conditions in reduced process streams. The 3R technology opens new ways for large industrial scale Anthracite Clean Coal production for small and medium sized power plants, up to 300 MW_e.

The prime environmental aspects of the 3R technology are the safety, prevention and comprehensive treatment. The 3R technology meets the EU and the U. S. environmental norms and standards for long term, including the U. S. RCRA Miscellaneous Units 40 CFR 264 Subpart X with the following main characteristics for the 3R thermal treatment unit:

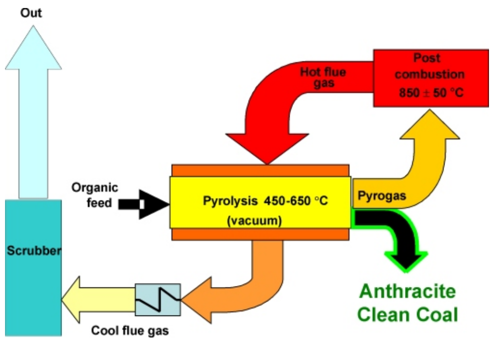

Figure 1. The 3R Anthracite Clean Coal process

– thermal desorption chamber: indirect-fired heat source used for primary desorption chamber, relatively low operating temperature,
– air pollution control devices (APCD): non-destructive APCD used,
– waste residual management: treatment of residuals is separate from the desorber,

whereas the primary desorption chamber, condensation or burning of pyrolysis gas--vapours, and non destructive APCD off gas scrubber are separate devices, whereas, treated solids, condensate residuals, APCD residuals, organic air emission, metal air emission, and the acid gas emission treatment are according to all the relevant comprehensive U. S. regulatory requirements for Operational Control, Residuals and Air Emission Parameters. The environmental purpose of 3R thermal desorption is to volatilize contaminant streams in small process gas volumes and to remove them from the treatment chamber for subsequent treatment. From permit legislative point of view it should be noted that the treatment standards in the U. S. relevant legislation Sec. 268.45 for thermal destruction specifically exclude thermal desorbers.

The 3R Anthracite Clean Coal is a product of man made low temperature carbonization process, where the natural process has been accelerated to convert low grade coals, such as low ash content brown coals and renewable biomass, to natural anthracite and coke comparable quality high grade coal. By expanding the anthracite like coal feed availability the 3R process opens new technical and economical opportunities for clean energy production. Extensive scientific and technical literature search made, including technological comparison of the innovative 3R *vs*. known solutions [reference short list 1-14].

The required amount of energy input is basically supplied from hot flue gases. The hot flue gases are produced in the combustion chamber for direct burn-off of the pyrolysis gas vapors and heats the reactor body from outside the mantel.

The burn of the pyrolysis gas vapors makes the process thermal energy self sustaining, but also utilizing the surplus energy from the exothermic decomposition process.

The exothermic process is a slow process; therefore the extended pyrolysis gas-vapour production will not result in an explosive production of gas-vapours.

The thermal engineering design of the 3R reactor is related to the through-put capacity of the reactor and the extremely qualitative variations of the input material. No matter if the basic material is of organic, inorganic and/or mixed character, the chemical components will be separated at a certain treatment temperature if the boiling point of the primary target contaminant component(s) are under 650 C.

The pyrolysis reactions are not only a sequenced series of reactions, but parallel series of reactions as well, with different levels of energy.

The 3R Clean Coal vessel has triple heat transfer mode from heat source to material, and the characteristics of the design provides maximum indirect heat transfer efficiency.

Therefore, the thermal conductivity of the different types of coal feed stream input material is of less importance and can be within a wider range.

Thermal decomposition phases

There are four well distinguished phases concerning the pyrolysis process inside the reactor, with consideration of material surface temperatures as follows:

(1) Warm up phase: up to 150-160 C. Characterized by the evacuation of the free and start of removal of the chemically bound water and volatile HAPs, such as S, Hg, and Cl, from the material.

(2) Thermal decomposition phase: from 160 up to 270-280 C. Characterized by heavy discoloration of the material, and the evacuation of the remaining chemically bounded water and HAP's, whereas HAP's have tendency to be removed from the material together with the aqueous solutions and light factions, with simultaneous development of gasification.

(3) Partial thermal desorption phase: from 280 up to 380-400 C. Characterized by self-carbonization with exothermic chemical reactions, partial gasification process and competition escape of approx. 50-55% volatile compounds from the material. Pyrolysis gas-vapour is continuously removed. Expected material core temperature is approx. 300-350 C.

(4) Stabilization phase: from 400 up to 500 C. Removal of the rest of the volatile content of the coal.

The 3R emission standards

The characteristics of the 3R low output volume emissions are that heavy metals and halogens are separated into two separated flows by true reductive thermal decomposition process, in vacuum, under low treatment temperature (tab. 1).

The main thermal desorption – pyrolysis process avoids creation of dioxin and furan gases D/F by its nature, re-creation of D/F by its construction design, flux of soot and particles into gas-vapor phase, unperfected burn out of organic components in the post combustion phase, flux of heavy metals into gas-vapor phase, oxidation of heavy metals in the solid phase, and creation of $SO_{x,}$ while reduces the creation of NO_x, CO, and CO_2 in the main process.

Table 1. The 3R process emission standards and comparison to other standards (Ref: EU FP5 NNE5/363/2002 report)

(293 K, 101,3 kPa, 11% O_2)

Target contamination	Units	US CFR 40 Part 60* DDDD**	IPR 5/3 UK 1996 EU 89/369/EEC	EU	17. BlmSchV Germany	**3R limits**
Dust	mg/Nm^3	70	30	10	10	**5**
THC (VOC)	mg/Nm^3	n. a.	20	10	10	**5**
HCl	mg/Nm^3	62	30	10	10	**5**
HF	mg/Nm^3	n. a.	2	1	1	**0.5**
SO_x as SO_2	mg/Nm^3	20	300	50	50	**10**
NO_x as NO_2	mg/Nm^3	388	350	200	100	**100**
CO	mg/Nm^3	157	100	50	50	**50**
Hg	mg/Nm^3	0.47	0.1	0.05	0.05	**0.05**
Cd	mg/Nm^3	0.04	0,1	0.05	0.05	**non detectable**
As, Cr, Cu, Ni	mg/Nm^3	n. a.	1.0	0.5	0.5	**non detectable**
Pb	mg/Nm^3	0.04	1.0	0.5	0.5	**non detectable**
PCDD/PCDF	mg/Nm^3	0.41	1.0	0.1	0.1	**non detectable**

* U. S. Code of Federal Regulations CFR 40 Part 60 emission standards for criteria pollutants from new stationary sources. Stationary source means any building, structure, facility, or installation which emits or may emit any air pollutant. 293 K, 101,3 kPa, 7% O_2 conditions (except opacity)

** Subpart DDDD – Emissions guidelines and compliance times for comercial and industrial solid waste incineration units that commenced on or before November 30, 1999

The 3R Anthracite Clean Coal technology impacts on the GHG climate programs

The 3R Anthracite Clean Coal technology opens new technical and economical solutions for climate policy that recognizes the need to take near-term (urgent) corrective actions, while maintaining economic growth that will improve the world's standard of living. The following advanced technical solutions offered by the 3R technolgy, all in order to support the CO_2 emission capture and safe storage programs in a sustainable way.

Preventive solid fuel pre-treatment – energy production-phase

(1) Phase separtion provides optimized burning = resulting less CO_2 generation – the reductive thermal desorption decomposition process provides separation of HAP's form Anthracite Clean Coal solid fuel stream in low process-gas volume, providing efficient and optimized burn off both the pyrolisis gas-vapours and clean coal, resulting total GHG emissions reduction in total.
(2) Les offgas volume with increased CO_2 concentration – the CO_2 concentration from the main unit is higher, but less in total volume.
(3) Clean offgases avoiding mixture of HAP's and GHG's – the GHG output form the main unit carried by cleansed offgases, so hazardous air pollutants will not be part of the CO_2 CCS operations, resulting better risk management.

Integrated CCS phase

The output gases form the pre-treatment energy production phase have optimal characteristics, such as cleansed gas performance, concentrated CO_2 and low in total volume which elements are efficiently integrated supporting the safe carbon capture and storage solutions. The 3R provides adda value for CCS techniques by providing monolithic homogenity and produce as low GHG volumes as it is possible. During the past years advanced GHG (from land based sources) storage techniques have also been developed, including but not limited for techniques such as:

- carbon capture and storage in sub-sea off-shore mainland geological structures (unminable coal beds, depleted oil and gas reserves, deep saline aquifers),
- improved oil recovery,
- oxycombustion for CO_2 capture, and
- aqueous mineral carbonation – conversion of gaseous CO_2 to solid carbonate (US DOE Mineral Carbonation Study Group).

However, concerns against GHG storage techniques, including the possibility of seepage, *e. g.* the physical release of the subsurface injected CO_2. As CCS zero emission seepage scientific models are theoretical, but the potential risk for early seepage is still a risk, therefore it is outmost important that the input CO_2 for injection into the CCS geological structures is rather clean, low in volume, and high in concentration, all in order to safety improve the optimized GHG storage conditions, while promoting the "once for all" stabilized fixation (incl. chemical adsorption and absorption, thermogenic conversion and mineral carbonation processes) of the CO_2, to the geological structure matrix. In this context the 3R technology offers significat safety improvements for the GHG-CCS conditions. Therefore, the combination of the 3R and CCS technology opens new perspectives for safer, better and less costly carbon capture and storage into geological structures, than know solutions today. The incremental coal utilization 3R technology provides less cost of electricity while sustainable carbon capture and storage made, when all costs included.

The 3R product-like pilot plant operations

The pilot plant has been developed, designed, and constructed for credible product like demonstration of the 3R technology critical components and its operation for potential and possible industrial partners (fig. 2). In order to make legislative demonstration the 3R pilot plant facility has been fully industrial operational permitted under EU norms and standards. The two years of permit procedure has been an important industrial demonstration to document the fact that the 3R Anthracite Clean Coal technology meets the new EU industrial and environmental legislations. The most important permitting authorities have been the following: Environmental Protection Authority, Industrial Safety Authority, Fire Protection Authority, Human Health Inspection Authority, and Building Construction Office.

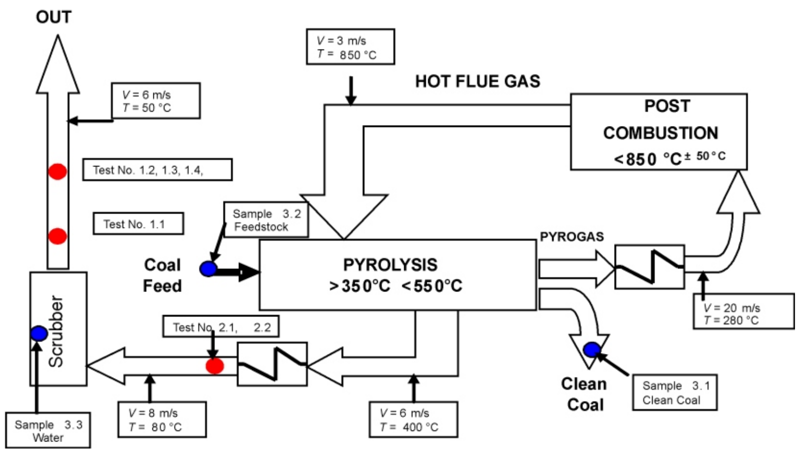

Figure 2. Clean Coal Pilot Plant Measurements and sampling points with process conditions (Ref: EU EP5 NNE5/363/2001 report)

The 3R pilot plant has been successfully tested in 2005 both for the equipment stable operation performance and end product quality by burning tests as well. The pilot test program consisting three major components:

(1) Pilot plant technology and equipment performance tests: period January 2005 through July 2005 (tab. 2).

Table 2. Pilot plant performance test program

Input	Output*	
	Clean Coal	By-products
100 m^3 brown coal of various types (<96 tons)	60 tons	Burnt gas-vapours: 36 tons
50 m^3 renewable biomass (15.4 tons) – straw – refuse grain – saw dust – animal bone meal	5 tons	Burnt gas-vapours: 10,4 tons
Total: 111,410 kg	Total: 65 tons	Total: 46.4 tons

* The end product output may very significantly by changed moisture content and input feed characteristics

(2) Clean Coal end product combustion and related comprehensive emissions tests: period April 2005 to July 2005.

(3) Pilot plant operation comprehensive emissions tests: period April 2005 to June 2005 (tabs. 3 and 4).

The pilot plant emission and Clean Coal end product combustion tests and evaluations are made by the University of Rostock in Germany (Chair of Energy Systems), the Chemical Process Engineering Research Institute – Center for Research and Technology Hellas in Greece (Solid Fuel Department, Ptolemais), and the Aristotle University of Thessalonici in Greece (Chemical Processing Engineering).

Table 3. Comparison of average flue gas emissions before and after scrubber: MSI 5600 Normalised for 11% O_2 (Ref: EU FP5 NNE5/363/2001 report)

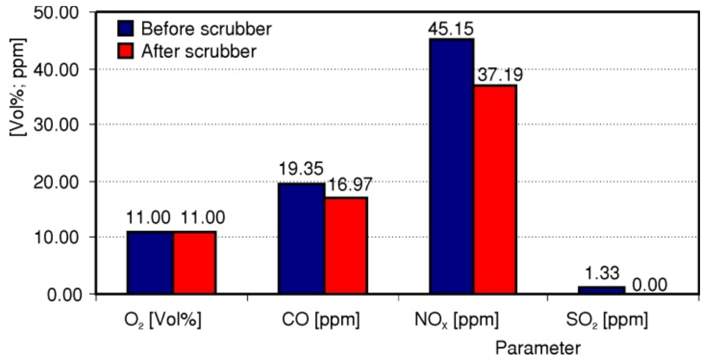

Table 4. Typical composition of brown coal and corresponding 3R Anthracite Clean Coal (Ref: EU EP5 NNE5/363/2001 report)

Brown coal*		3R Anthracite Clean Coal
Water	<20%	<1%
Volatile matter	30-35%	<5%
Carbon	35%	70-85%
Ash	approx. 10-15%	approx. 15-30%
Organic sulphur	>1%	<0.15%
Energy content	10-14 MJ/kg	>27 MJ/kg

* Through including renewable biomass to the process flow and/or by combination with other technologies, such as arc-fired and oxyfuel, the 3R technology also makes climate relevant contribution to the reduction of GHG such as CO_2. The GHG reduction is directly proportional to the biomass ratio (on a calorific value basis) in the Anthracite Clean Coal. The low volume of pirolysis process gases also provides results for decrease of total GHG emissions. The 3R climate policy recognizes the need to take near-term actions and offers constructive solution for GHG reduction, while maintaining economic growth that will improve the world's standard of living

3R pilot plant emission control by the Chemical Process Engineering Research Institute, Center for Research and Technology Hellas in Greece (Solid Fuel Department, Ptolemais,) and the Aristotle University of Thessalonici (Chemical Processing Engineering), Greece (2005) (Ref: EU FP5 NNE5/363/2001 report)

3R pilot plant emission control by the University of Rostock (Chair of Energy Systems), Germany (2005) (Ref: EU FP5 NNE5/363/2001 report)

Process limitation factors

(1) high input ash content,
(2) high alkali content in feed (Na, Ca, K). These fuel constituents reduce the ash softening point and cause slagging in the combustion chamber and fouling of the heat exchangers,
(3) high input moisture content (over 18%), for which case pre dry is required, and
(4) add-on technology needed for GHG – carbon dioxide recycling.

Economical and market aspects

The 3R Anthracite Clean Coal technology replaces oil and prolongs fossil fuel use. The 1% available Anthracite Clean Coal natural reserve is expanded to commonly available compatible quality Clean Coal reserve, made of the widely available low grade brown coals.

As the prevention by 3R is safer, better, and less costly than the "end-of-the-pipe" solutions, there are significant environmental winnings with the technology applications towards near zero emission. The green wins include significantly reduced hazardous air pollution emissions (Hg, Cl, S, PAH, PCCD/PCDF), reduced green house gas emissions, better residual treatment, and less boiler corrosion, which all support the long term sustainability of the 3R technology.

The price of the high grade coals basically follows the price of oil and gas. The 3R treatment provides a highly profitable economical method for utilizing low quality coal reserves. The estimated technology life time period is 2005-2025.

The estimated price gap between low grade and high grade coal is 25-40 $/t in 2005, which price gap – due to the more strict global environmental normative – is expected to significantly rise to higher levels over time. The 3R pre-treatment option technology in industrial scale is already economical from 25 $ through-put tons price gap*.

In total, the 3R Anthracite Clean Coal technology decreases the energy production costs for the users, when all costs are calculated under open market conditions for the industry.

The level of cost reduction might change from case to case and it is highly depending on the available input brown coal feed quality, preferably with low ash content, and the local industrial and economical environment. Techno-economical case feasibility study is to be developed case by case.

Table 5. Price assessment

Prices*		2000	2001	2002
Steam coal	€/tce**	42	53	45
Browncoal / Lignite	€/tce	9.63	9.5	9
2 ton Browncoal / Lignite	€/2tce	19.26	19	18
Difference	**€/tce**			**27**

* German Coal Importers Association Annual Report 2002

** tce = ton coal equivalent

The economic advantage comes from the price difference between the raw resource "low quality brown coal" and "added value Clean Coal".

The carbonization process will in average result in a weight loss of over 50%. This means that for every ton clean coal about 2 tons raw material is necessary. This gives a price difference in the range over 30€/t. This price difference covers the costs for 3R carbonization, plant overheads and profits. The addition of biomass to form CMF must take into account the higher biomass feedstock prices. The average biomass feedstock costs in Germany is estimated in 2005 of 48 €/t without transport.

* Subject to availability of optimal feed material and interlink option to main boiler technology; base year 2005

The 3R product-like pilot plant operation pictures

The 3R Anthracite Clean Coal product-like pilot plant main unit: indirectly heated rotary kiln (2005)

Post burner and off-gas treatment units (2005)

Post burner (2005)

Post burner inner chamber inspection window at operational temperature 850 C (2005)

The legal status of the 3R anthracite clean coal technology

The sole inventor, the sole owner of the 3R technology, engineering design, know how, intellectual property rights and pilot plant industrial site and equipment is the Swedish inventor Edward Someus. In US method apparatus and patented are (US 5 707 592). Other 3R technology related patents have been developed by Edward Someus.

Conclusions

The preventive pre-treatment of low grade solid fuels is safer, faster, better, and less costly *vs*. the end-of-the-pipe post treatment solutions. The 3R (Recycle-Reduce-Reuse) integrated environment control technology provides preventive pre-treatment of low grade solid fuels, such as brown coal and contaminated solid fuels to achieve high grade fuels. The 3R technology may be applied as vital component for an integrated strategy towards near zero emission targets to combine technologies for environmentally sustainable and economical solid fuel power generation, including but not limited to the decrease or even removal of output green house gases, such as CO_2.

The 3R Anthracite Clean Coal end product may advantageously be used in the oxyfuel and boiler technologies.

The 3R technology may advantageously be integrated to the oxyfuel – oxy-firing, Foster Wheeler anthracite arc-fired utility type boiler and Heat Pipe Reformer technologies in combination with CO_2 capture and storage programs.

The 3R technology is efficient for significant decrease or even removal of hazardous air pollutants from coal and organics feed stream by carbonization means, even in those case when the feed is of variating in flow, composition and concentration of toxic input elements. Important element of the feed selection strategy is the low ash and low moisture content.

For pre-treatment a specific purpose designed, developed and patented pyrolysis technology used, 3R, consisting of a horizontally arranged externally heated rotary kiln, post burned and off-gas treatment scrubber, where the contaminated feed material is carbonized and decomposed in true reductive environment under less than 850 C material temperature and vacuum. Low process gas volume generated.

The flexible operation provides wide range of 25 to 125% of nominal capacities. The volatile hazardous air pollutants are safely removed in the reduced volume of gas-vapour stream and burned out in the post burner at 850 C$^{2s\ 50\ C}$, while the Clean Coal solid end product is utilized for clean energy production.

Concerning economy, the estimated price gap between low grade and high grade coal is 25-40 $/t in 2005, which price gap – due to the more strict global environmental normative – is expected to significantly rise to higher levels over time. The 3R pre-treatment option technology in industrial scale is already economical from 25 $ per through-put tons price gap.

Product like pilot plant with 100 kg/h through-put capacity has been built and successfully tested and demonstrated in Hungary in 2005.

The 3R advantages are the feedstock and technology flexibility, near zero pollutants for hazardous air pollutants, cost reduction and cost decrease of overall production costs when all real costs are calculated and improved safety.

The 3R-CCS is seen as part of the portfolio to mitigation options towards zero emission, such as improvements on the energy efficiency, total HAP control, fuel switching, fuel flexibility, secure fuel supply, and energy production cost decrease.

Acknowledgment

The past three years scientific research works and construction of the 3R pilot plant has been carried out under the framework of the EU FP5 contract NNE 5/363/2001

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Author's address:

E. Someus
Terra Humana Clean Technology Engineering Ltd.
59, Szechenyi St., H-1222 Budapest, Hungary

E-mail: edward@terrenum.net
Web site: www.terenum.net

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